Research Article

Cross-validity of one maximum repetition predictive equation for men with spinal cord injury

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Objectives: The study aimed to test the cross-validation of a specific one maximum repetition (1RM) predictive equation based on the 4- to 12-maximum repetition test (4-12RM) for men with spinal cord injury (SCI).
Study design: Cross-sectional study.
Setting: Rehabilitation Hospital Network.
Participants: Fifty-eight men aged 31.9 (20.0–38.0) years (median and quartile) with SCI were enrolled in the study.
Interventions: None.
Outcomes measures: Volunteers were tested in 1RM test or 4-12RM of the bench press exercise with 2–3 interval days in a random order. The intraclass correlation coefficient (ICC) with Bland Altman plot was used to compare a specific predictive equation (SPE) and six current predictive equations (CPE) based on the 4- to 12-maximum repetition with the 1RM test.
Results: The SPE showed the highest intraclass correlation coefficient (ICC = 0.91; 95%CI 0.85–0.95), the smallest range of the interval around the differences (Δ = 36.6) and the second lowest mean difference between 1RM test and 1RM predictive equation (−2.4 kg). The CPE3 presented the lowest mean difference (−1.6 kg). All intraclass correlations' predictive equations were classified as excellent.
Conclusion: The SPE presented a suitable and satisfactory validity to assess men with SCI at the bench press exercise. Thus, the equation is an accurate method to predict 1RM in SCI.

Keywords: Resistance training, Muscle fatigue, Rehabilitation, Exercise test, Strength training, Muscle strength

Introduction

Strength is considered essential for individuals with spinal cord injury (SCI),[1] particularly to carry out their basic activities of daily living.[2] In this population, maintaining strength facilitates wheelchair propulsion, pressure relief, and transfers.[3–5] Also, it is associated with an increased cardiovascular capacity,[6,7] exercise tolerance,[6] reduction in shoulder pain,[8] and improved health.[9]

An accurate assessment of maximum strength is important to determine the workloads that should be used in the design of training programs and to assess the results of an intervention.[7] The one maximum repetition (1RM) test is the maximum weight lifted once in a controlled manner, and it is considered a benchmark in dynamic strength evaluation and widely used for determination of the intensity of strength training.[7,10]

However, several investigators have reported difficulties in 1RM test execution in gyms, physical training and rehabilitation clinics.[10–13] Among the factors that limit the utilization in these environments is the lack of valid criteria for establishing the initial overload (i.e. first trial) and the total time spent in its performance.[14] The 1RM assessment has also been associated with increased risk of injury depending on the population, and it is demanding more time.[10–13] For some populations, age and preexisting medical conditions may be contraindications to the safe completion of 1RM testing.[12] During the last few years, some 1RM-predicting equations have been suggested to avoid direct

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DOI 10.1080/10790268.2018.1547861

measurement procedures.[12,14,15] The most recent equation based on the 4- to 12-maximum repetition test (4-12RM) was a specific predictive equation (SPE) performed in individuals with SCI.[16] The specific predictive equation presented a high *R*-square and a low standard error of estimation for the measured 1-RM.[16]

However, the cross-validity of the SPE with another set of individuals with SCI was not assessed. Cross-validation consists of ascertaining that an empirically developed predictor measure, works when applied to a new sample.[17] Unless a study is replicated at least once with similar results, little confidence can be placed in the predictor measurement. Cross-validation studies are extremely important, since prediction instruments developed and validated in specific populations, may present reduced validity when applied to diverse clinical settings.[18]

The present study aimed to test the cross-validation of a specific one maximum repetition predictive equation, based on the 4- to 12-maximum repetition test for men with SCI. This study hypothesizes that the specific predictive equation will present a suitable and satisfactory validity to assess men with SCI.

Methods

Design

This prospective, cross-sectional study involved two testing sessions on non-consecutive days. The study was approved by the Institutional Ethics Committee (number 13326213.7.0000.0022) and all participants provided written informed consent to participate in the study. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research.

Participants

The men with SCI were consecutively enrolled in the study. They were participants in a rehabilitation program of a Rehabilitation Hospital and were recruited during the second week of rehabilitation. Before the rehabilitation program, the patients were not participating in physical activities. The data collection period was from April 2016 to December 2017.

Individuals unable to participate in the rehabilitation program, with a history of metabolic disorders, and with a history of cardiovascular, cardiac, or orthopedic surgery that would restrict their ability to execute tests or perform correct exercise biomechanics were excluded from the selection process. Therefore, the following inclusion criteria were used: male (older than 18 years), diagnosis of traumatic SCI, complete motor lesion (ASIA Impairment Scale [AIS] grade A or B)[19] and clinical stability. The International Standards for Neurological Classification of Spinal Cord Injury published by American Spinal Injury Association (ASIA) was used to assess the motor level of the individuals with spinal cord injury by a trained physiotherapist.[19]

Procedures

Before testing, participants were informed about all procedures and were instructed regarding the execution techniques.

Body composition assessment

On the first day of testing, participants underwent a body composition assessment. During this evaluation, body mass (BM), height (cm), skinfold sum (ΣSF), and body fat percentage (%Fat) using the skinfold protocol were measured.[20] Brachial biceps, brachial triceps, and subscapular and suprailiac sites were used in the Durnin and Womersley skinfold equation for body fat percentage prediction.[16,21] Pectoral, midaxillary, abdominal, thigh and leg sites were also measured to calculate the skinfold sum.

Maximum strength tests

Maximum strength tests (1RM and 4-12RM) were executed using bench press exercises on a bench that was 26 cm wide and 123 cm long. This exercise is considered the best-isolated assessment to predict total dynamic strength,[22] upper limb strength,[7] and loads for tests and exercises.[7] The barbell is 3.1 kg and 1.84 cm. The weights range from 0.5 to 20.0 kg. Participants were instructed to refrain from eating or smoking for 3 hours before the tests, to not perform the strenuous exercise for 6 h before the tests, and to empty their bladder before the tests.

Bench press exercises were performed in the supine position with the participant's feet on the ground. The hips and legs of the participants were stabilized with straps (Fig. 1).

Each repetition had four phases: (1) extended elbows and hands holding the bar; (2) elbow flexion and horizontal shoulder extension (eccentric phase for approximately 2 seconds); (3) light touch of the barbell at the mesosternal point; and (4) elbow extension and horizontal shoulder flexion (concentric phase). During the first repetition, two physical educators put the barbell in the participant's hands. Grip width was measured with elbows at 90 degrees and arms parallel to the ground. The mesosternal point was marked before execution, and no physical support was allowed during valid repetitions.

Figure 1 Position of the participants in the bench press. Bandages and strips were used at trunk and legs to stabilization.

The maximum strength tests were assessed by the same tester and were performed randomly with 48- and 72-hour intervals to avoid accumulated fatigue.[23]

One maximum repetition test

Before the 1RM test, participants performed a warm-up of 5–10 repetitions with 50% of the perceived maximum load. After 1 minute of rest, 3–5 repetitions with 70% of the perceived maximum load were performed.[14] The perceived maximum load was estimated based on researcher and participant perceptions.

After the warm-up, the participant rested for 2 min, the load was increased, and the exercise was performed. After a 5-minute interval, the load was increased or decreased to allow only one repetition. The maximum number of attempts during the same session was five according to the procedure described in the literature.[14,15,22]

Four- to twelve-maximum repetition test

The same warm-up protocol for the 1RM test was performed. The initial load used was approximately 80% to 90% of the maximum perceived load.[14,15,22] The participants were instructed to perform the possible lifts until concentric movement failure and each subject moved at their own selected pace. The number of repetitions was supposed to be at least 4 and at most 12. Otherwise, a new attempt was performed after 5 minutes of rest. The load was decreased if the repetition number was less than 4 or increased if it was more than 12. The maximum number of attempts during the same session was five according to the procedure described in the literature.[14,15,22] The load and repetitions were inserted at the SPE:[16]

$$1\text{RM} = 1.942 + 1.102 \times 4\text{–}12\text{RM (kg)} + 0.414 \times 4 - 12\text{RM (repetitions)}$$

Statistical analysis

Data normality assumptions were verified by the Shapiro-Wilk test. For the height and fat percentage, the assumptions were met, and the data are presented as mean (and standard deviation). For the other variables, data were non-parametric and presented as median and quartiles (25%; 75%).

To assess the cross-validation, we used the intraclass correlation coefficient (ICC) with Bland Altman statistics and plots.[24] Bland Altman plot analysis is a simple way to evaluate a bias between the mean differences and to estimate an agreement interval, within which 95% of the differences of the second method, compared to the first one, fall. Data can be analyzed both as unit differences plot and as percentage differences plot.[25] In our study, the differences between the measurements with specific predictive equation (SPE) based on the 4- to 12- maximum repetition and 1RM test were plotted against the mean of both measurements. Limits of agreement were calculated as the mean difference ± 1.96 standard deviations of the difference. According to the limits of agreement method, it was decided prior to the conduction of the study that the maximally acceptable absolute difference between SPE and 1RM test could be 3%.

The ICC was classified based on Cicchetti standards: below 0.40 – level of clinical significance is poor; 0.40–0.59 – fair; 0.60–0.74 – good; 0.75–1.00 – excellent.[26] Confidence intervals of 95% (95%CI) were used between comparisons.

The SPSS (version 22.0; IBM SPSS Statistics) statistical package was used for data processing. In the absence of multiple comparisons, statistical significance was set at $P < 0.05$.

Results

A total of 58 men with SCI were recruited with median age (percentiles 25 and 75) 31.9 years (20.0–38.0) voluntarily participated in the study. The complete demographic and clinical data of the participants are presented in Table 1.

Table 1 Subjects demographics.

	C5 to L2
Age (years)	31.9 (20.0–38.0)
TSI (months)	36.9 (10.8–136.0)
Body mass (kg)	65.8 (56.0–78.6)
Height (cm)	172.6 (±7.7)
BMI (kg/m^2)	21.7 (19.0–27.2)
ΣSF (mm)	145.0 (82.3–199.9)
%Fat	22.2 (±8.3)

Notes: Height and fat percentage are exhibited by mean (standard deviation). Other variables are show by median (percentiles 25 and 75). BMI, body mass index; SCI, spinal cord injury; TSI, time since injury; ΣSF, skinfolds sum; %Fat, fat percentage.

Table 2 Bland and Altman method and intraclass correlation coefficient (ICC) comparing 1RM test and specific predictive equation.

	Total			
	MD (percentiles 25 and 75)	Δ	ICC	95%CI
SPE	−1.5 (−10.6 to 2.1)	36.6	0.91*	0.85–0.95

Notes: The confidence interval was set on 95% (95%CI). 1RM: one maximum repetition test; MD = median difference between 1RM test and 1RM predictive equation (kg); SPE, specific predictive equation; Δ = range of the interval around the differences (± 1.96 SD).*P ≤ 0.01.

The Bland and Altman analysis pointed that the SPE presented 36.6 of a range of the interval around the differences (Δ = 36.6) and −1.5 kg of median difference between 1RM test and 1RM predictive (Table 2, Fig. 2).

The specific predictive equation revealed that intraclass correlation coefficient with 1RM test (ICC = 0.91; 95%CI 0.85–0.95) was excellent based on Cicchetti standards (Table 2).

Discussion

The present study tested the cross-validation of a specific one maximum repetition predictive equation, based on the 4- to 12- maximum repetition test for men with SCI. Our results showed that specific predictive equation was valid to assess this population at this exercise. This equation presented that intraclass correlation coefficient with 1RM test was excellent.

Ribeiro Neto *et al.* demonstrated accurate and reliable data concerning various predictive equations in bench press 1RM results in individuals with SCI.[27] Only Schwingel *et al.*[11] tested and compared twelve predictive equations in the bench press with individuals with motor disabilities. However, besides the small sample size (total of nine), the authors did not include individuals with SCI demonstrating the necessity of specific strength assessment studies for this population. The study's results showed that the predictive equation had the mean difference ranging from −18.0 to −8.1 and Brzycki predictive equation[28] presented the lowest result.[11] However, our results showed that the SPE was the lower median difference (MD = −1.5 kg) and excellent intraclass correlation coefficient (ICC = 0.91).

The validity of SPE can be explained by its ability to minimize the interference of an SCI on other estimations of 1RM bench press. One of these characteristics is the

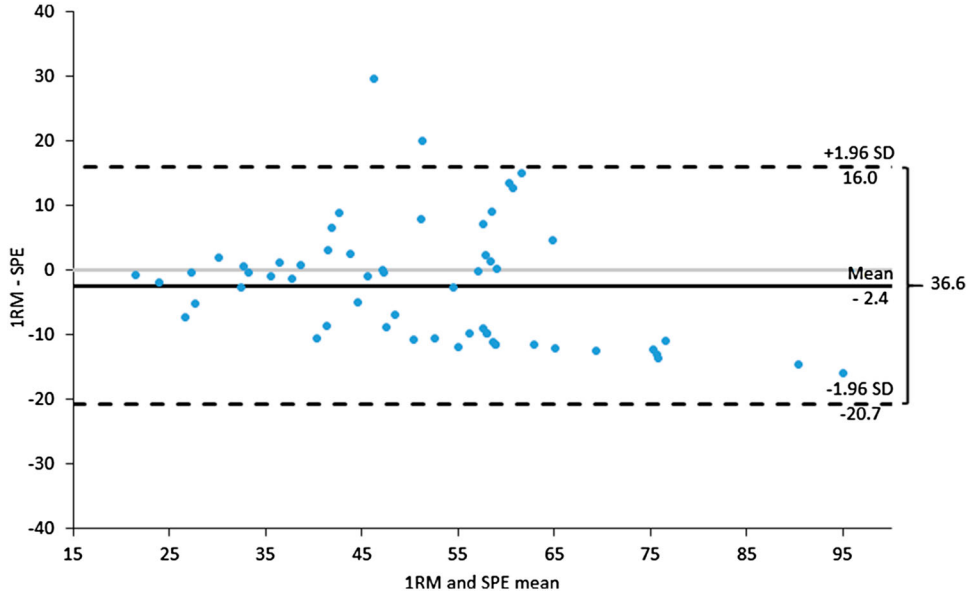

Figure 2 Bland and Altman method comparing 1RM test and specific predictive equation. The confidence interval was set at 95% (95%CI). 1RM: one maximum repetition test; ±1.96 SD: range of the interval around the differences at one.

reduced, posture stabilization due to impairment or absence of, leg strength and worse trunk balance.[19,29] The individuals with higher injury level, such as the tetraplegia and high paraplegia groups presents the reduced, or the absence of, strength in the abdominal muscles.[19,29] Also, triceps muscle strength in individuals with injury level higher than C7 myotome is reduced. All these characteristics could alter posture stabilization and correct positioning, and, consequently, could influence the bench press maximum load. Similarly, the pectoralis major, brachial triceps, and deltoids are the primary muscles used during bench press exercises and this movement pattern has limitations when generalizing to other tests of movement or functional independence.[27]

The study, however, had certain limitations. First, our subjects were consecutively enrolled and were not randomly recruited from the rehabilitation hospital. Secondly, the patients showed time since injury median higher than three years. Therefore, our results may have some difference when using individuals with acute spinal cord injury. Lastly, our study used a median difference between 1RM test and 1RM predictive, in other words, non-parametric assessments for the Bland Altman test.

Conclusion

This study concluded that specific prediction equation is valid to assess men with SCI at the bench press exercise. Thus, the equation is an accurate method to predict 1RM in SCI. The validation of this equation allows its use in rehabilitation and strength training, assisting the evaluation and prescription of this training in individuals with SCI.

Disclaimer statements

Contributors Both authors contributed to all phases of this study including design, data collection and analysis and writing up. The final version of the manuscript has been approved by both authors.

Funding This work was done without receiving any financial support from any third party.

Conflicts of Interest The authors report no conflicts of interest.

Ethics approval The study was approved by the Institutional Ethics Committee (number 13326213.7.0000.0022).

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